PATENT

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For

METHODS AND APPARATUSES FOR FILTERING PULSES

by

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CROSS-REFERENCE(S) TO RELATED APPLICATION(S)

This application claims priority to U.S. Provisional Patent Application Serial No. 60/437,170, filed December 13, 2002, the entire contents of which are expressly incorporated by reference.

REFERENCE TO APPENDIX

This application includes a computer program listing appendix, submitted on compact disc (CD). The content of the CD is incorporated by reference in its entirety and accordingly forms a part of this specification. The CD contains the following files:

File name: mainforperiodicpulsefilter.txt File Size: 35.1 kb
File name: cyclicfilterlarge.txt File Size: 6.8 kb
Creation date for CD: June 25, 2003

BACKGROUND OF THE INVENTION

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1. Field of the Invention

The invention relates generally to the field of signal processing. More particularly, the invention relates to a method and apparatus for filtering pulses.

2. Discussion of the Related Art

Typical data acquisition systems may include sensors (or transducers) and signal conditioning elements used to transform analog signals into digital data for further processing by a computer, processor, or the like. Such systems may be useful in a variety of applications including, for example, digital communications and pulse detection.

Unfortunately, data acquisitions systems are often subject to electrical noise or interference, causing the resulting digital data stream to include unwanted information. For example, periodic pulse interference is a common problem in pulse detection applications. One solution to this problem involves detecting the undesired periodic pulses and filtering them out of the data stream.

Prior art techniques require all of the data stream – that is, desired and undesired pulses – to be passed on to the processor. The processor then filters out the undesired pulses in software. A problem with this technology is that it requires a high performance processor to keep up with the data streams. Another problem with this technology is that it requires a high bandwidth communications link between the digital front-end and the processor.

SUMMARY OF THE INVENTION

In one embodiment, the invention is a method that includes creating a filter structure using a parameter of a periodic pulse train, the filter structure having a plurality of time slots, each time slot being associated with a memory value; receiving a pulse at a time; incrementing the memory value associated with the time slot corresponding to the

time the pulse was received; filtering the pulse if the memory value exceeds a threshold; and transmitting the pulse to a processor if the memory value does not exceed the threshold. Other embodiments of the present methods are described below.

In another embodiment, the invention is an apparatus that includes an input filter; a pulse detection circuit coupled to the input filter; a periodic pulse filter coupled to the pulse detection circuit, the periodic pulse filtering circuit operable to use a parameter to create a filter structure, the filter structure having a plurality of time slots, each time slot being associated with a memory value, receive a pulse, increment the memory value associated with the time slot corresponding to the time the received pulse arrived, and filter the pulse if the memory value exceeds a threshold; and a pulse queuing and transmission circuit coupled to the periodic pulse filter. Other embodiments of the present apparatuses are described below.

BRIEF DESCRIPTION OF THE DRAWINGS

The following drawings demonstrate aspects of the present methods and apparatuses. They illustrate by way of example and not limitation. Like reference numbers refer to similar elements.

FIG. 1 is a block diagram of one embodiment of a pulse processing system suitable for use with the present methods and apparatuses.

FIG. 2 is a diagram of one embodiment of a periodic pulse filter structure suitable for use with the present methods and apparatuses.

FIG. 3 is a flowchart of one embodiment of a periodic pulse filtering method suitable for use with the present methods and apparatuses.

FIG. 4 is a graph of filtered and unfiltered simulated data streams, illustrating an aspect of the invention.

DETAILED DESCRIPTION

In this document (including the claims), the terms "comprise" (and any form of comprise, such as "comprises" and "comprising"), "have" (and any form of have, such as "has" and "having"), and "include" (and any form of include, such as "includes" and "including") are open-ended linking verbs. For example, a method "comprising" creating a filter structure using a parameter of a periodic pulse train; receiving a pulse at a time; incrementing the memory value associated with the time slot corresponding to the time the pulse was received; filtering the pulse if the memory value exceeds a threshold; and transmitting the pulse to a processor if the memory value does not exceed the threshold is a method that possesses at least these steps, but is not limited to possessing only these steps.

Similarly, an apparatus "comprising" an input filter; a pulse detection circuit coupled to the input filter; a periodic pulse filter coupled to the pulse detection circuit; and a pulse queuing and transmission circuit coupled to the periodic pulse filter is an apparatus that possesses at least these structures, but is not limited to possessing only these structures. For example, this apparatus also covers an apparatus that possesses an analog-to-digital converter coupled to the input filter.

The terms "a" and "an" are defined as one or more than one. The term "another" is defined as at least a second or more. The term "coupled" is defined as connected, although not necessarily directly, and not necessarily mechanically. The term "approximately" is defined as at least close to a given value (e.g., preferably within 10% of, more preferably within 1% of, and most preferably within 0.1% of). The term "program" and "computer program" are defined as a sequence of instructions designed for execution on a computer system.

Those of ordinary skill in the art will appreciate that in the detailed description below, certain well known components and assembly techniques have been omitted so that the invention is not obscured in unnecessary detail.

The invention may include a method and apparatus for filtering out a periodic pulse embedded in a data stream. A "periodic pulse" is defined as a pulse in a periodic pulse train. In one exemplary embodiment, the invention may include a digital front-end that removes the periodic pulse before the data stream is sent to a pulse processor, thus decreasing the processor load and reducing the communications bandwidth requirement between the digital front-end and the processor.

Referring to **FIG. 1**, a block diagram of one embodiment of a pulse processing system **100** is depicted. Analog signal **101** is detectable by sensor **102**. Sensor **102** is coupled to amplifier **103**. Amplifier **103** is coupled to analog-to-digital converter **104**. Analog-to-digital converter **104** is coupled to input filter **106** of digital front-end circuit **105**. Input filter **106** is coupled to pulse detector circuit **107**, and pulse detector circuit **107** is coupled to periodic pulse filter **108**. Periodic pulse filter **108** is coupled to pulse

data queuing and transmission circuit **109**, and pulse data queuing and transmission circuit **109** is coupled to processor **110**. Processor **110** is also coupled to periodic pulse filter **108**.

In one exemplary embodiment, analog signal **101** may be an electromagnetic signal such as light or a laser, and sensor **102** may be a photodiode. Processor **110** may be a pulse processor, a digital signal processor (DSP), a computer, or the like.

In practice, digital front-end circuit **105** may be an integrated circuit or a programmable circuit, such as, for example, a programmable logic device (PLD), a field-programmable gate array (FPGA). When digital front-end circuit **105** is a programmable circuit, a program, such as that presented below and discussed in detail with reference to **FIG. 3**, creates an apparatus in accordance with the present invention that operates in accordance with methods of the present invention. In the alternative, digital front-end circuit **105** may be hard-wired or may use predetermined data tables, or may be a combination of hard-wired and programmable circuitry.

When in operation, sensor **102** transforms analog signal **101** into an electrical signal to be amplified by amplifier **103**. The amplified signal is converted into a digital signal by analog-to-digital converter **104**, and enters digital front-end **105** via input filter **106**. Input filter **106** may be, for example, a high-pass filter to correct for an undesirable effect resulting from an analog-to-digital conversion. Next, the signal is fed into pulse detection circuit **107**, which identifies pulses and delivers an unfiltered data stream to periodic pulse filter **108**. At periodic pulse filter **108**, a periodic pulse is filtered

out of the data stream and the resulting filtered data stream is transmitted to processor **110** via pulse data queuing and transmission circuit **109**.

In one embodiment, processor **110** may identify a periodic pulse train in the data stream, extract parameters from the periodic pulse train, and feed the extracted parameters to digital front-end **105**. Specifically, processor **110** may identify periodic pulses by the pulse repetition frequency (PRF) of the periodic pulse train and send one or more parameters to periodic pulse filter **108**, where the parameters sent may include: a time slot width, a number of time slots, a modification parameter, and a filter threshold. Periodic pulse filter **108** may then implement a periodic filter structure that divides time into slots as detailed in **FIG. 2**.

Referring to **FIG. 2**, a diagram of one embodiment of a periodic pulse filter structure **200** is depicted. Periodic filter structure **200** may divide time into, for example, 20 time slots of substantially equal width. In other embodiments, structure **200** may include hundreds or thousands of time slots.

Referring to **FIGS. 1** and **2**, the number of slots and the slot width of filter structure **200** may be included in parameters provided to periodic pulse filter **108** by processor **110**. In one embodiment, the width of each slot is determined by the maximum jitter in the periodic pulse train. In another embodiment, the total length (in time) of structure **200** is approximately equal to the inverse of the pulse repetition frequency (or pulse repetition interval (PRI)) of the periodic pulse train. A modification parameter, also provided to periodic pulse filter **108** by processor **110**, may modify the width of the last time slot in structure **200** (slot number 20) in order to approximately match the structure

length with the pulse repetition interval of the periodic pulse train, causing its periodic pulses to always fall into the same time slot.

Referring to **FIG. 3**, a flowchart of one embodiment of a periodic pulse filtering method **300** is depicted. Method **300** may be performed by periodic pulse filter **108** of digital front-end **105** as detailed in **FIG. 1**.

In step **301**, a pulse is received. Next, a time slot, such as the one depicted as part of filter structure **200** of **FIG. 2**, is assigned to the pulse in step **302**. Then, a value in memory corresponding to the slot is incremented by step **303**, and control passes to step **304**. If a memory value corresponding to the slot exceeds a filter threshold, the pulse is deleted by step **307**. Otherwise the pulse is transmitted to a processor by step **305**. The algorithm waits for the next pulse to arrive in step **306**.

In one embodiment, method **300** is repeated several times. Each time a pulse falls into a time slot, its value in memory may be incremented. Because the periodic pulse train delivers its pulses always on the same time slot, after a few iterations the memory value corresponding to the slot may exceed the filter threshold and the corresponding periodic pulse may be filtered out of the data stream. In one embodiment, the filter threshold value is provided to periodic pulse filter **108** of **FIG. 1** by processor **110**. A non-periodic pulse train, or a periodic pulse train that has a PRI value different from the filter structure **200** length (detailed in **FIG. 2**), is not filtered out because the time distribution of its pulses is approximately uniform among all slots.

In another embodiment, a background process may run continuously and attenuate all memory values associated with each time slot, such that if the periodic pulse train

stops, the filter no longs blocks any pulses. The background attenuation process combined with the spreading of non-periodic pulses may prevent slot values from exceeding the filter threshold, thus allowing non-periodic pulses to be transmitted to the processor. In yet another embodiment, another periodic pulse filter similar to the one detailed above may be used simultaneously so that multiple periodic pulse trains may be filtered. Moreover, three or more periodic pulse filters may be used consistent with the present methods and apparatuses to filter multiple periodic pulse trains.

Software or computer instructions configured to carry out one or more steps of method **300** may be loaded onto a computer readable medium. One of ordinary skill in the art will understand that computer readable medium may take many forms, including any data storage device that can store data that can thereafter be read by a processor, a computer or a computer system, including, for example, a disk, such as a floppy disk, a zip disk, or the like; read-only memory; random access memory; CD-ROMs; magnetic tape; optical data storage devices, SMARTMEDIA ® cards; flash memory; compact flash memory; and the like. The computer readable medium can also be distributed over network-coupled computer systems so that the computer readable instructions are stored and executed in a distributed fashion. For example, the computer readable medium may also take the form of a carrier wave such as, for example, signals on a wire (e.g., signals downloaded from the Internet) or those that are transmitted electromagnetically or through infra red means.

Shown in the computer program listing appendix (*see* CD) is an exemplary source code written in Altera Hardware Description Language that is suitable for carrying out

steps described above, and which may be used in conjunction with a field programmable gate array (FPGA) such as, for example, the APEX 20KE FPGA (EP20K200E) from Altera Corporation. The code is an example of how to filter a digital pulse according to the methods detailed in **FIG. 3** and described above. This code is exemplary and does not limit the scope of the claims. It simply represents one specific embodiment for carrying out steps associated with the present methods and is included for the convenience of the reader in this regard. Those of ordinary skill in the art having the benefit of this disclosure will recognize that a wide variety of computational techniques and/or different types of corresponding source code may be used in implementing the present methods.

Table I illustrates an implementation of a 20-slot pulse filter over ten cycles. In this example, the filter structure is tuned to a periodic signal that falls into the seventh slot. The total length of the structure is approximately equal to the PRI of the periodic pulse train to be filtered.

Table I

Pulse Filter Implementation

	Filter Cycles									
Slot Number	1	2	3	4	5	6	7	8	9	10
1	0	0	10	8	6.4	5.12	4.96	3.28	2.62	12.1
2	0	0	0	0	0	0	0	0	0	0
3	10	8	6.4	5.12	14.1	11.3	9.02	7.22	5.77	4.62
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	10	8	6.4
6	0	0	0	0	0	0	0	0	0	0
7	10	18	24.4	29.5	33.6	36.9	39.5	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0
12	0	10	8	6.4	5.12	14.1	11.3	9.02	7.22	5.77
13	0	0	0	0	0	0	0	0	10	8
14	0	0	0	0	0	0	0	0	0	0
15	0	0	0	10	8	6.4	5.12	4.1	3.28	2.62
16	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	10	8	6.4	5.12

Still referring to **Table I**, in this particular example, the filter threshold is set to 40. Thus, when the value in memory associated with the seventh slot exceeds 40 (during the eighth cycle), the pulse is deleted. All other pulses falling in slots 1-6 and 8-20 are

non-periodic or have a period different than the length of the filter, and are spread among these slots. Due to the attenuation factor from the background process, the memory values associated with slots 1-6 and 8-20 do not reach the threshold.

Referring to **FIG. 4**, a graph of filtered and unfiltered simulated data streams **400** is depicted illustrating an aspect of the invention. The horizontal axis is time, and the vertical axis is the amplitude. An unfiltered data stream **401** containing two pulse streams at different frequencies is processed by a filter operating with a structure tuned to one of the frequencies (undesired) as described above. The resulting filtered data stream **402** contains only the desired frequency.

The individual components described above need not be made in the exact disclosed forms, or combined in the exact disclosed configurations, but could be provided in any suitable form, and/or combined in any suitable configuration. It will also be clear to those of ordinary skill in the art that substitutions, modifications, additions and/or rearrangements of the features of the inventive methods and devices may be made without deviating from their scope, which is defined by the claims and their equivalents. The appended claims are not to be interpreted as including means-plus-function limitations, unless such a limitation is explicitly recited in a given claim using the phrase(s) "means for" and/or "step for," respectively.